TECHNICAL MEMORANDUM

LANDAU ASSOCIATES
ENVIRONMENTAL | GEOTECHNICAL | NATURAL RESOURCES

TO: Washington State Department of Ecology

FROM: Landau Associates, Inc.

DATE: June 11, 2002

RE: PROTECTIVE MEASURE COST ESTIMATES

INTRODUCTION

In accordance with the scope of work and deliverable schedule for contract number C0200196, this technical memorandum develops planning level cost estimates to implement a range of protective measures to address area-wide soil contamination by arsenic and lead in Washington State. The protective measures that are evaluated in this memorandum are those that were retained for further evaluation in the May 31, 2002 technical memorandum entitled *Management Area Categories and Protective Measures* (Landau Associates 2002). The costs were estimated using a cost model developed on a Microsoft Excel spreadsheet that incorporates the main cost components applicable to each protective measure. The cost model spreadsheet is included with this submittal to facilitate development of cost estimates for a specific protective measure at a specific management area. The cost model was used to estimate cleanup costs for each of the protective measures applied to each of the three categories of management areas that were identified in the above-referenced technical memorandum.

This technical memorandum is organized into the following sections:

- Background: Presents background information on the area-wide project including an overview of the main conclusions from the May 31, 2002 technical memorandum.
- Assumed Management Area Conditions: Presents assumed conditions for each of the three management area categories to allow estimation of implementation costs.
- Detailed Description of the Physical Protection Measures: Describes each of the physical protection measures to provide a basis for the cost estimates.
- Physical Protection Measures Cost Estimate: Describes the cost model and presents the results of applying the model to the three management area categories.
- Physical Protection Measures Cost Estimate Sensitivity Analysis: Discusses the cost assumptions that have the greatest impact on the calculated cost.
- Institutional Protection Measures: Presents available cost data on institutional protection measures.

The cost estimates presented in this technical memorandum are considered planning level estimates and should only be used to compare the relative costs of applying the protective measures to

each of the three management area categories. Although the cost estimates are intended to be within a range of -30 to +50 percent of actual costs for most management areas (subject to the applicability of the assumed management area conditions), management area-specific conditions and contractor-specific variables will determine the actual cost of applying these protective measures to a given management area. The costs and cost model presented in this memorandum are not intended to replace obtaining actual quotations from qualified contractors to implement a specified protective measure at a specific management area.

BACKGROUND

The Departments of Ecology, Agriculture, and Health, and the Office of Community Development (the Agencies) chartered a Task Force to address issues of area-wide soil contamination by arsenic and lead in Washington State. This task force is working with two work groups and a consultant team to develop recommendations to the chartering agencies for responding to area-wide soil contamination. The information provided in this technical memorandum is one step in the process to develop a statewide strategy for responding to widespread, low-to-moderate level arsenic and lead contamination in soil in Washington State.

For each management area, the following process was established for identifying recommended protective measures:

- Define categories of management areas at which low-to-moderate soil contamination by arsenic and/or lead may be present.
- Identify protective measures that may be applicable to address low-to-moderate concentrations of arsenic and/or lead in soil.
- Estimate costs for implementing each protective measure.
- Identify soil cleanup standards and applicable, relevant, and appropriate requirements (ARARs) for each protective measure.
- Evaluate the residual human health and environmental risks associated with each protective measure.
- Evaluate protective measures using the MTCA evaluation criteria and identify the most practicable final protection measure for each category of management area. Also, recommend interim protection measures for each category of management area based on their effectiveness in reducing exposure to soil contaminants.

This technical memorandum addresses the third bullet listed above. The May 31, 2002 technical memorandum addressed the first two bullets, defining management area categories and identifying

protective measures. The following three management area categories were defined in the May 31, 2002 technical memorandum:

- **Industrial/Commercial Management Areas:** These are areas currently used or planned to be used for industrial or commercial purposes. In general, people do not live at these areas, food is not grown at these areas, and much of the areas are (or will be) covered with structures or pavement. It is assumed that, at these areas, exposure to contamination within the soil to humans, and particularly children, is limited. These areas are referred to as industrial areas in this memorandum.

- **Other Management Areas Prior to Development:** These areas include future single- or multi-family residences, parks, schools, day-care centers, etc., where exposure by adults and children is likely if no protective measures are implemented. This category also includes former agricultural areas where future use is not yet determined. These areas have limited infrastructure (e.g., no buildings, few or no roads, and possibly no utilities). These areas are referred to as pre-development areas in this memorandum.

- **Other Management areas After Development:** These areas are currently used for single- or multi-family residences, parks, schools, day-care centers, etc. These areas already are developed and contain infrastructure such as buildings, roads, utilities, paved areas, etc. Contaminated soil at these areas may be used to grow foods or may be contacted by children and adults. These areas are referred to as post-development areas in this memorandum.

Protective measures were identified and retained for further evaluation in the May 31, 2002 technical memorandum. Seven of these protective measures can be categorized as physical protection measures; these seven protective measures are shown in bold font in Table 2. The remaining protective measures are institutional protection measures. Institutional protection measures include measures such as land use regulations, easements, restrictive covenants, and education/community protection measures.

ASSUMED MANAGEMENT AREA CONDITIONS

This section expands on the general descriptions provided above to define a typical management area within each management area category to facilitate calculation of estimated protective measure costs. The expanded descriptions include definition of the following conditions: management area size, depth of contamination, percentage of management area covered by existing pavement or structures, and the area containing exposed contaminated surface and near-surface soil (equal to the management area size less that portion covered by pavement or structures). Groundwater is assumed to be unaffected by the contaminated soil. The management area descriptions are summarized in Table 1.

The range of contaminated soil depths is based on the typical range in which arsenic and lead-contaminated soil has been observed in existing areas impacted by area-wide soil contamination in Washington State. The conditions presented above represent the minimum information needed for cost estimation. Other data will be needed to evaluate the feasibility of a specific protective measure at an

identified management area (e.g. soil type, concentration of arsenic and lead, management area access and use).

DETAILED DESCRIPTION OF PHYSICAL PROTECTION MEASURES

This section expands on the general descriptions of the physical protection measures that were retained in the May 31, 2002 technical memorandum to provide a basis for the cost estimates presented in the following section. Specific physical protection measures are identified as Options 1 through 7 as shown in Table 2. Several of the options are further divided into sub-options identified as Option 1A, 1B, 2A, etc. as shown in Table 2.

In addition to the cost components described below, all of the physical protection measure options include costs for implementing a management area investigation to delineate the extent of soil contamination. All of the options, except Options 4C, 4D, and 7, include allowances for protective measures design and planning, contractor mobilization, part-time construction oversight by an environmental professional, confirmation sampling (if needed), administration and reporting, and a 10 percent contingency to cover unforeseen costs. These cost elements were not included in Options 4C, 4D, and 7 because of the small scale and limited level of difficulty associated with these protective measures. None of the options include removal of significant existing management area features (e.g. buildings, pavement, trees, large shrubs) to gain access to contaminated soil. Removal and replacement of such features, if necessary, may significantly increase the estimated costs. If contaminated soil is present under such features and the features are left in place, institutional protection measures may be needed to address the contaminated soil. This example illustrates the likelihood that two or more of the protective measure options described below may need to be combined to fully address the contamination conditions at a given management area.

None of the options, with the exception of phytoremediation, include costs for long-term maintenance (e.g. watering and mowing) of vegetated surfaces; these costs are considered incidental to the normal management area use. The overall unit cost provided for phytoremediation includes long-term watering, harvesting, replanting, and disposal associated with this protective measure.

Option 1: Excavation and Offsite Disposal

Option 1A: Excavation and Disposal at a Subtitle D landfill with no pre-treatment requirements

Option 1A consists of excavating contaminated soil, transporting the soil to an approved Subtitle D landfill (i.e. non-hazardous waste landfill), disposing of the soil at the landfill, replacing the excavated

soil with clean fill (except at pre-development management areas) and establishing a vegetated surface over the excavated area. Excavation at the industrial and pre-development management areas assumes that conventional earthmoving equipment (e.g. backhoes and excavators) will be used. Excavation at the smaller post-development management areas assume that 80 percent of the soil will be removed using small earthmoving equipment (e.g. bobcat) and the remainder by hand shoveling. It is also assumed that the excavated soil is loaded directly into dump trucks and that 5 hours is needed per dump truck load for loading and round-trip transportation to and from the landfill.

The primary difference in calculating costs for the three Option 1A management area categories is that a higher excavation unit cost was used for the post-development management areas category due to the assumed use of less efficient excavation methods. In addition, establishing a vegetated surface at post-development management areas consists of sodding the disturbed areas; establishing vegetated surfaces at the industrial and pre-development management areas consists of hydroseeding the disturbed areas.

Option 1B: Excavation and Disposal at a Subtitle D landfill with Stabilization/Solidification pre-treatment requirements

This option is identical to Option 1A with the exception that the soil is classified as a State Dangerous Waste and therefore requires pretreatment at the landfill using stabilization/solidification prior to disposal. Because the closest landfill with an associated stabilization/solidification facility is located in Arlington, Oregon, it is assumed that 12 hours is needed per dump truck load for loading and round-trip transportation to and from the landfill**.** All other cost elements of Option 1A apply to Option 1B.

Option 2: Phytoremediation

Option 2 consists of establishing sufficient plant growth on contaminated soil to promote the uptake of arsenic and lead from the soil into the aboveground portion of the plant. This form of phytoremediation, referred to as phytoaccumulation or phytoextraction, would rely on certain plants called hyperaccumulators to absorb unusually large amounts of metals in comparison to other plants. These plants would be selected and planted at a management area based on the type of metals present and other applicable management area conditions. After the plants have been allowed to grow for several weeks or months, they would be harvested and then landfilled. The planting and harvesting of plants would be repeated as necessary to reduce soil contaminant levels to acceptable levels.

At this point in the process of identifying recommended protective measures, specific details on the application of phytoremediation to address area-wide arsenic and lead soil contamination (i.e. types of plants, duration of treatment) and the effectiveness of this protective measure have not been established. These issues will be evaluated later in the protective measures selection process. In addition, phytoremediation is an emerging technology and little full-scale cost information on the technology exists. For these reasons, the unit cost used for phytoremediation in the cost model represents a general phytoremediation unit cost range obtained from the literature as opposed to development of a unit cost from individual cost components.

Option 3: In-Situ Stabilization/Solidification

Option 3A: In-situ Stabilization/Solidification Using Cement Binders

Option 3A consists of physically encapsulating the contaminated soil within a Portland cement matrix using in-situ (i.e. in-place) stabilization/solidification to form a monolithic block. The in-situ stabilization/solidification process would include first removing and disposing of the upper vegetated surface layer and then mixing the contaminated soil with Portland cement, water, and potentially other performance-enhancing additives. The equipment used for mixing would depend on the mixing depth. For mixing below 2 ft, a rotating mixer head attached to an excavator or a vertical auger would likely be used. For mixing from the surface to 2 ft, conventional tilling equipment would likely be used and hand operated roto-tillers could be used for smaller management areas with shallow (less than 6 inches) soil contamination. This option would also include importing 4 inches of topsoil and establishing a vegetated surface over the treatment area as described for Option 1.

The primary difference in calculating costs for the three Option 3A management area categories is that a higher stabilization/solidification unit cost was used for the post-development management areas due to the assumed smaller treatment area which results in the need to use less efficient stabilization/solidification equipment.

Option 3B: In-situ chemical Stabilization/solidification of Lead-Contaminated Soil Using Phosphate

This option is similar to Option 3A with the exception that the soil is mixed with a phosphate additive to chemically bind soluble metals into stable, insoluble minerals. This form of in-situ chemical stabilization is also referred to as phosphate-induced metal stabilization (PIMS) and in-place inactivation in the literature. This option has been shown to be effective at reducing the bioavailability of lead in soil, however, additional studies are ongoing to determine its effectiveness on arsenic. Because this

technology relies more on chemical stabilization than physical encapsulation to bind contaminants, the treated soil remains in a granular form as opposed to a more solid, monolithic form described above for Option 3A. For this reason, Option 3B does not include placement of a topsoil layer over the treated soil. However, establishment of a vegetated surface, as described for Option 1, is included.

Similar to Option 3A, a slightly higher unit cost is assumed for the post development management areas due to the use of less efficient stabilization/solidification equipment.

Option 4: In-situ Capping

Option 4A: In-situ Capping With a Pavement Surface

Option 4A consists of placing asphalt pavement over contaminated soil to reduce potential exposure pathways. This option includes removing the upper vegetated surface, limited grading, and placing a 6-inch crushed rock base coarse layer and a 2-inch asphalt pavement layer. Option 4A for the industrial and pre-development management areas includes an allowance for construction of a hard-pipe drainage network over the capped area due to the larger size of these management areas and the need to provide adequate drainage. A 30 percent higher paving unit cost was used at post development management areas to reflect the reduced efficiency when paving small areas relative to large open areas.

Option 4B: In-situ Capping With an Engineered Soil Cover

Option 4B consists of placing a soil cover over the contaminated soil to reduce potential exposure pathways. The soil cover would include a geotextile fabric placed directly on top of the contaminated soil to act as a marker and barrier separating the underlying contaminated soil from the clean fill of the soil cover. Six inches of topsoil would then be placed on top of the geotextile fabric. A vegetated surface would be established, as described for Option 1. This option also includes limited site grading. No significant differences exist in the unit costs used between the three management area categories for this option.

Option 4C: In-situ Capping with a Vegetated Surface Cover

This option consists of establishing a vegetated surface on top of existing exposed soil to reduce the direct exposure pathway of exposed contaminated soil. This option includes a surface preparation step (e.g. thatching) followed by hydroseeding. This option does not include placement of a geotextile marker or additional fill on top of the existing surface.

Option 4D: In-situ Capping with a Wood Chip Surface Cover

This option is similar to Option 4C with the exception that a geotextile marker and a 3 inch layer of wood chips (i.e. beauty bark) would be placed over the exposed contaminated soil to reduce the direct exposure pathway.

Option 5: Ex-Situ Capping

Option 5A: Ex-situ Capping With a Pavement Cover
Option 5B: Ex-situ Capping With an Engineered Cover
Option 5C: Ex-situ Capping With a Vegetated Surface Cover
Option 5D: Ex-situ Capping With a Wood Chip Surface Cover

Options 5A through 5D are similar to options 4A through 4D except it is assumed that the contaminated soil in a management area is excavated and then consolidated on another area of the management area under one of the four covers described above for Options 4A through 4D. It is assumed that the consolidated soil occupies an area that is one-third the size of the original contaminated surface area, therefore, the average thickness of the consolidated soil will be approximately three times the thickness of the contaminated soil in its original location. Options 5A through 5D also include replacing the excavated soil with clean fill (except for pre-development management areas) and establishing a vegetated surface over the excavated area. The descriptions of the covers provided above for Options 4A through 4D also apply to Options 5A through 5D.

Option 6: Tilling/Soil Blending

This option consists of mixing near-surface contaminated soil with cleaner soil located below the contaminated soil to reduce the concentration of contaminants in the newly formed surface soil. It is assumed that mixing occurs to a depth that is three times the thickness of the contaminated soil layer. For example, if a management area contains a 6-in. layer of contaminated soil at the surface, this soil would be mixed with clean soil down to 1.5 ft below ground surface to obtain an average 67 percent reduction in contaminant concentration. Mixing down to 2 ft would be conducted using conventional soil tilling equipment common to the farming industry. For mixing below 2 ft, a rotating mixer head attached to an excavator, a vertical auger, or ex-situ mixing in a pile using an excavator would likely be used. Higher unit costs for tilling are used for the post-development management areas management area category due

to the use of less efficient soil mixing equipment and methods. This option also includes establishing a vegetated surface over the treated area as described for Option 1.

Option 7: Fencing

This option consists of installing a 6-ft high, chain link fence with associated gates around a management area to control access to the management area. The shape of the management area will affect the length of fence needed, therefore, it is assumed that each management area is rectangular with the long sides twice as long as the short sides.

PHYSICAL PROTECTION MEASURES COST ESTIMATE

The following discussion of the physical protection measures cost estimates is divided into a section on the cost model used to develop the estimates and the cost estimate results.

Cost Model

As previously discussed, a cost model using an Excel spreadsheet was developed to estimate costs to apply each of the seven physical protection measure options to each of the three management area categories. The cost model is included with this submittal as an electronic, read-only file with file name "Protective_Measure_Cost_Model." However, sending this file electronically may remove the read-only status; we recommend the recipient re-establish this file as a read-only document upon receipt. The user can make changes to the file but the file must be saved as a new file to protect the integrity of the original model.

Two independent options exist for calculating protective measure implementation costs using the model. The first option is to use the worksheet labeled "Pg1" which calculates and presents costs for each protective measure based on the main parameters that are entered in the highlighted cells at the top of the worksheet (e.g. management area type, area and depth of contamination) and a set of default unit costs. The default unit costs used in all of the calculations are listed on the sheet labeled "ref" which also describes the basis for the unit costs. Additional variables that may be adjusted by the user include the percentage of excavation performed by hand (for post-development management areas), the percentage of area consolidation for ex-situ capping, the indirect or markup costs for the remedy, and the over-excavation factor for soil tilling/blending.

The second option for calculating protective measure implementation costs using the model is to access the worksheets labeled "PM1A" through "PM7" (i.e. PM1A = Protective Measure 1A). These

worksheets present all of the cost components and unit costs that are used as input to calculate the implementation cost for each protective measure at each of the three management area types. Although worksheets PM1A through PM7 obtain default unit costs from the "ref" worksheet similar to the "Pg1" worksheet, these unit costs and other input variables can be over-written to allow the user greater flexibility in adjusting input variables to estimate costs for a specific management area. It is noted that worksheets PM1A through PM7 are independent of the variables that are inputted on worksheet Pg1.

Cost data used in the cost model were obtained from several sources including:

- Actual cost data from implementing residential yard cleanups in the vicinity of the former Asarco-Everett smelter
- The R.S. Means Company publication "*Environmental Remediation Cost Data – Assemblies*, 7th Edition"
- Technology-specific cost data obtained through review of available literature including published case studies available through U.S. EPA and the Federal Remediation Technologies Roundtable (FRTR)
- Contractors and technology developers
- The previous project experience of Landau Associates personnel.

Cost Estimate Results

The results of applying the cost model are summarized in Tables 3 through 5, which present the total costs to implement each protective measure at each of the three management area categories for the three specified depth intervals: 0-0.5 ft, 0-1.5 ft, and 0-3 ft. The tables also present the unit costs to implement the protective measure on the basis of acres of contaminated surface area. As previously discussed, all costs are intended to be within a range of -30 to +50 percent of actual costs subject to the assumptions used to develop the estimates. Although a single cost is presented in Tables 3 through 5 for ease of use, the user should be aware that application of a -30 to +50 percent cost range around the costs shown is appropriate. This cost range is used to reflect the large degree of variability and uncertainty in estimating the cost to implement these protective measures and the large variability in potential management area conditions. The implementation cost of these protective measures could fall outside of this –30% to +50% range at some management areas, especially those employing less-demonstrated technologies such as phytoremediation and in-situ chemical stabilization. Itemized cost spreadsheets detailing the derivation of the costs shown in Tables 3 through 5 for each protective measure are provided in Attachment 1.

As shown in Tables 3 through 5, the lowest cost protective measure option for each management area category is Option 7, fencing, and the highest cost option is Option 1B, excavation and disposal at a Subtitle D landfill with stabilization/solidification pretreatment. Option 1A, excavation and disposal at a Subtitle D landfill without pretreatment is typically at least one-half to one-third the cost of Option 1B.

PHYSICAL PROTECTION MEASURES COST ESTIMATE SENSITIVITY ANALYSIS

This section discusses the cost assumptions that have the greatest impact on the calculated costs of each of the protective measures. For each option, these are the area and/or depth of contaminated soil to be addressed. The area of exposed contaminated soil is a function of the percent of the management area that is not covered by structures or pavement. The cost model spreadsheet is designed to allow easy adjustment of these factors. It is important to reiterate that none of the options include removal of significant existing management area features (e.g. buildings, pavement, trees, large shrubs) to gain access to contaminated soil. Removal and replacement of such features, if necessary, may significantly increase the estimated costs. In addition, none of the options, with the exception of phytoremediation, include costs for long-term maintenance of the protective measures (e.g. watering and mowing of caps, asphalt pavement, or wood chip replacement). Including some or all of the long-term maintenance costs could significantly impact the overall cost. Additional important cost assumptions for each of the protective measure options are discussed below.

Option 1: Excavation and Offsite Disposal

As stated earlier, the estimated costs for this option will likely be underestimated if the travel time from the management area to the ultimate disposal site is greater than previously assumed. Conversely, costs may be overestimated if the travel time is less than assumed. In addition to the cost assumptions and factors discussed earlier regarding the need for stabilization/solidification prior to disposal and the distance between the management area and the landfill, the following additional factors will affect the cost to implement this option:

- Trees, buildings, underground utilities, significant topographic relief, and other interferences limit management area access and, therefore, dictate that excavation be completed using more costly methods. In the cost model spreadsheet it is assumed that excavation at industrial/commercial and pre-development management areas would allow virtually unimpeded excavation using large equipment such as dozers and scrapers. For post-development management areas it was assumed that 80 percent of the excavation would be performed using small equipment such as a bobcat, and that 20 percent of the excavation would be performed using hand shovels. Higher costs will be incurred the more that less efficient excavation methods using smaller equipment (i.e. hand digging) are used.

- A soil density greater than the assumed 1.5 tons/cubic yard will increase the cost for transportation and disposal.

- The cost estimate for pre-development management areas does not include replacing excavated soil with clean fill because it is assumed that the property will be re-graded as part of development. The cost for clean fill should be included if this assumption is not valid.

- The unit costs used in the cost model spreadsheet require a minimum quantity of soil to be valid. For example, the transportation cost for excavated soil assumes a minimum of 30 tons (full truck and pup combination). The cost per ton will be higher if less than full loads are transported.

Option 2 - Phytoremediation

The cost of phytoremediation will be impacted by the following factors:

- High concentrations of arsenic and lead will require a longer treatment duration or potentially the need to blend the soil prior to phytoremediation. The unit cost used for phytoremediation was based on a 5- to 10-year treatment duration.

- The unit cost to landfill the harvested plants may be very high if the plants contain such high metals concentrations so as to be considered a dangerous waste.

- The limited use of the land undergoing treatment during the treatment period (which could require 5 or more years) may represent other costs incurred by the landowners that are not accounted for in this cost model.

Option 3 - In-Situ Stabilization/Solidification

The cost of in-situ stabilization/solidification will be affected by the following factors:

- The same management area access factors described above for Option 1 also apply to this option.

- Because in-situ stabilization/solidification using cement binders typically results in an increased volume of treated soil (i.e. bulking) in the range of 5 to 15 percent, additional management area work may be needed to allow for an increase in the ground surface elevation. If the ground surface elevation cannot be raised due to management area uses, then offsite disposal of some of the solidified or non-solidified soil would need to be added to the cost estimate.

- The soil concentrations of lead and arsenic will influence the overall project cost. For example, if the concentrations only slightly exceed target levels and have low leachable metals concentrations, then less binder will be needed.

- Because this process does not remove or destroy the contaminants, long-term management or monitoring of the soil may be needed, resulting in additional costs. No long-term management costs have been provided in the cost model.

Option 4 - In-Situ Capping

The cost of in-situ capping will be affected by the following factors:

- The same site access factors described above for Option 1.
- In-situ capping is more cost effective where the surface area of metals impacted soil is relatively small and the depth is relatively large.
- The geotextile liner(s) selected for the base of the cap. Thinner and non-reinforced liners would cost less but provide less protection to punctures from digging and may provide less warning to excavation workers. The cost spreadsheet assumes the use of a fairly thick (130 mil) geotextile fabric.
- Because this process does not remove or destroy the contaminants, long-term management or monitoring of the soil may be needed, resulting in additional costs. No long-term management costs have been provided in the cost model.

Option 5 - Ex-Situ Capping

The cost of ex-situ capping will be affected by the following factors:

- The same site access factors described above for Option 1
- The cost will be significantly affected by the degree to which soil can be consolidated. The cost model assumes that the impacted soil will be consolidated to reduce the surface area to be capped by two thirds (67%). This factor can be adjusted in the spreadsheet.
- Because this process does not remove or destroy the contaminants, long-term management or monitoring of the soil may be needed, resulting in additional costs. No long-term management costs have been provided in the cost model.

Option 6 - Tilling/Soil Blending

- The same site access factors described above for Option 1
- The cost for tilling/soil blending will depend on the concentration of metals in the soil and the required depth of mixing that is needed to achieve a target concentration level.
- Weather and climate conditions would affect cost. Tilling dry soil on a hot windy day would require much greater effort to suppress dust compared to tilling damp soil on a humid day with no wind.

Option 7 – Fencing

- Management areas that have a greater perimeter length than that obtained from assuming a rectangular property and a 2:1 ratio of long sides to short sides will require additional fencing and a higher cost.

INSTITUTIONAL PROTECTION MEASURES

Four typical institutional protection measures were described and retained for further evaluation in the May 31, 2002 technical memorandum. These measures included land use regulations, easements, restrictive covenants, and education/community protection measures. Development of costs to implement these institutional protection measures consisted of reviewing cost information obtained as part of the information survey and Institutional Frameworks evaluation of five area-wide contamination case studies. Implementation of one or more institutional protection measures was carried out at each of the five case study sites. However, little actual data exists on the cost to implement these measures. A description of the institutional protective measures implemented and the available cost data to implement these measures are listed in Table 6.

TABLE 1
ASSUMED MANAGEMENT AREA CONDITIONS

	Management Area Category		
Management Area Condition	**Industrial/Commercial Management Areas**	**Other Management Areas Prior to Development**	**Other Management Areas After Development**
Property size	10 ac	5 ac	0.2 ac
Depth of contamination (three depths assumed)	0.5/1.5/3 ft	0.5/1.5/3 ft	0.5/1.5/3 ft
Percent of management area covered by pavement or structures	80%	0%	50%
Contaminated area of management area	2 ac	5 ac	0.1 ac

TABLE 2

PROTECTIVE MEASURE OPTIONS

Protective Measure Option No.	Description
1	**Excavation and offsite disposal**
1A	Excavation and disposal at a Subtitle D landfill with no pre-treatment requirements.
1B	Excavation and disposal at a Subtitle D landfill with stabilization/ solidification pretreatment.
2	**Phytoremediation**
3	***In situ* stabilization/solidification**
3A	*In situ* stabilization/solidification using cement binders
3B	*In situ* chemical stabilization/solidification of lead-contaminated soil using phosphate
4	***In situ* capping**
4A	*In situ* capping with a pavement surface
4B	*In situ* capping with an engineered soil cover
4C	*In situ* capping with a vegetated surface
4D	*In situ* capping with a wood chip surface
5	***Ex situ* capping**
5A	*Ex situ* capping with a pavement surface
5B	*Ex situ* capping with an engineered soil cover
5C	*Ex situ* capping with a vegetated surface
5D	*Ex situ* capping with a wood chip surface
6	**Tilling/soil blending**
7	**Fencing**

Table 3
Summary of Costs for Protective Measures
Industrial/Commercial Management Areas

Protective Measure	0.5 ft Depth		1.5 ft Depth		3.0 ft Depth	
	Total Cost ($)	Unit Cost ($/acre)	Total Cost ($)	Unit Cost ($/acre)	Total Cost ($)	Unit Cost ($/acre)
1A - Excavation and Disposal at a Subtitle D Landfill	$ 200,000	$ 100,000	$ 550,000	$ 275,000	$ 1,100,000	$ 550,000
1B - Excavation, Offsite Solidification/Stabilization, and Disposal at a Subtitle D Landfill	$ 540,000	$ 270,000	$ 1,570,000	$ 785,000	$ 3,100,000	$ 1,550,000
2 - Phytoremediation	$ 230,000	$ 115,000	$ 500,000	$ 250,000	$ 900,000	$ 450,000
3A - In-Situ Solidification Using Cement Binders	$ 210,000	$ 105,000	$ 500,000	$ 250,000	$ 930,000	$ 465,000
3B - In-Situ Chemical Stabilization of Lead-Contaminated Soil Using Phosphate	$ 180,000	$ 90,000	$ 470,000	$ 235,000	$ 900,000	$ 450,000
4A - In-Situ Capping with an Asphalt Pavement Surface	$ 320,000	$ 160,000	$ 320,000	$ 160,000	$ 320,000	$ 160,000
4B - In-Situ Capping with an Engineered Soil Cover	$ 100,000	$ 50,000	$ 100,000	$ 50,000	$ 100,000	$ 50,000
4C - In-Situ Capping with a Vegetated Surface	$ 17,000	$ 8,500	$ 17,000	$ 8,500	$ 17,000	$ 8,500
4D - In-Situ Capping with a Wood Chip Surface	$ 42,000	$ 21,000	$ 42,000	$ 21,000	$ 42,000	$ 21,000
5A - Ex-Situ Capping with an Asphalt Pavement Surface	$ 190,000	$ 95,000	$ 330,000	$ 165,000	$ 540,000	$ 270,000
5B - Ex-Situ Capping with an Engineered Soil Cover	$ 120,000	$ 60,000	$ 260,000	$ 130,000	$ 460,000	$ 230,000
5C - Ex-Situ Capping with a Vegetated Surface	$ 120,000	$ 60,000	$ 250,000	$ 125,000	$ 460,000	$ 230,000
5D - Ex-Situ Capping with a Wood Chip Surface	$ 110,000	$ 55,000	$ 240,000	$ 120,000	$ 450,000	$ 225,000
6 - Tilling/Soil Blending	$ 47,000	$ 24,000	$ 180,000	$ 90,000	$ 330,000	$ 165,000
7 - Fencing	$ 32,000	$ 16,000	$ 32,000	$ 16,000	$ 32,000	$ 16,000

Note: Values have been rounded to two significant figures.

Table 4
Summary of Costs for Protective Measures
Pre-Development Management Areas

Protective Measure	0.5 ft Depth Total Cost ($)	0.5 ft Depth Unit Cost ($/acre)	1.5 ft Depth Total Cost ($)	1.5 ft Depth Unit Cost ($/acre)	3.0 ft Depth Total Cost ($)	3.0 ft Depth Unit Cost ($/acre)
1A - Excavation and Disposal at a Subtitle D Landfill	$ 410,000	$ 82,000	$ 1,100,000	$ 220,000	$ 2,200,000	$ 440,000
1B - Excavation, Offsite Solidification/Stabilization, and Disposal at a Subtitle D Landfill	$ 1,300,000	$ 260,000	$ 3,700,000	$ 740,000	$ 7,300,000	$ 1,460,000
2 - Phytoremediation	$ 580,000	$ 116,000	$ 1,200,000	$ 240,000	$ 2,200,000	$ 440,000
3A - In-Situ Solidification Using Cement Binders	$ 500,000	$ 100,000	$ 1,200,000	$ 240,000	$ 2,300,000	$ 460,000
3B - In-Situ Chemical Stabilization of Lead-Contaminated Soil Using Phosphate	$ 420,000	$ 84,000	$ 1,100,000	$ 220,000	$ 2,200,000	$ 440,000
4A - In-Situ Capping with an Asphalt Pavement Surface	$ 810,000	$ 162,000	$ 810,000	$ 162,000	$ 810,000	$ 162,000
4B - In-Situ Capping with an Engineered Soil Cover	$ 260,000	$ 52,000	$ 260,000	$ 52,000	$ 260,000	$ 52,000
4C - In-Situ Capping with a Vegetated Surface	$ 42,000	$ 8,400	$ 42,000	$ 8,400	$ 42,000	$ 8,400
4D - In-Situ Capping with a Wood Chip Surface	$ 110,000	$ 22,000	$ 110,000	$ 22,000	$ 110,000	$ 22,000
5A - Ex-Situ Capping with an Asphalt Pavement Surface	$ 400,000	$ 80,000	$ 570,000	$ 114,000	$ 820,000	$ 164,000
5B - Ex-Situ Capping with an Engineered Soil Cover	$ 220,000	$ 44,000	$ 390,000	$ 78,000	$ 640,000	$ 128,000
5C - Ex-Situ Capping with a Vegetated Surface	$ 210,000	$ 42,000	$ 380,000	$ 76,000	$ 630,000	$ 126,000
5D - Ex-Situ Capping with a Wood Chip Surface	$ 180,000	$ 36,000	$ 350,000	$ 70,000	$ 610,000	$ 122,000
6 - Tilling/Soil Blending	$ 110,000	$ 22,000	$ 430,000	$ 86,000	$ 820,000	$ 164,000
7 - Fencing	$ 53,000	$ 10,600	$ 53,000	$ 10,600	$ 53,000	$ 10,600

Note: Values have been rounded to two significant figures.

Table 5
Summary of Costs for Protective Measures
Post-Development Management Areas

Protective Measure	0.5 ft Depth Total Cost ($)	0.5 ft Depth Unit Cost ($/acre)	1.5 ft Depth Total Cost ($)	1.5 ft Depth Unit Cost ($/acre)	3.0 ft Depth Total Cost ($)	3.0 ft Depth Unit Cost ($/acre)
1A - Excavation and Disposal at a Subtitle D Landfill	$ 16,000	$ 160,000	$ 38,000	$ 380,000	$ 72,000	$ 720,000
1B - Excavation, Offsite Solidification/Stabilization, and Disposal at a Subtitle D Landfill	$ 33,000	$ 330,000	$ 89,000	$ 890,000	$ 170,000	$ 1,700,000
2 - Phytoremediation	$ 12,000	$ 120,000	$ 25,000	$ 250,000	$ 45,000	$ 450,000
3A - In-Situ Solidification Using Cement Binders	$ 25,000	$ 250,000	$ 47,000	$ 470,000	$ 79,000	$ 790,000
3B - In-Situ Chemical Stabilization of Lead-Contaminated Soil Using Phosphate	$ 29,000	$ 290,000	$ 50,000	$ 500,000	$ 83,000	$ 830,000
4A - In-Situ Capping with an Asphalt Pavement Surface	$ 22,000	$ 220,000	$ 22,000	$ 220,000	$ 22,000	$ 220,000
4B - In-Situ Capping with an Engineered Soil Cover	$ 8,000	$ 80,000	$ 8,000	$ 80,000	$ 8,000	$ 80,000
4C - In-Situ Capping with a Vegetated Surface	$ 2,000	$ 20,000	$ 2,000	$ 20,000	$ 2,000	$ 20,000
4D - In-Situ Capping with a Wood Chip Surface	$ 3,000	$ 30,000	$ 3,000	$ 30,000	$ 3,000	$ 30,000
5A - Ex-Situ Capping with an Asphalt Pavement Surface	$ 16,000	$ 160,000	$ 28,000	$ 280,000	$ 45,000	$ 450,000
5B - Ex-Situ Capping with an Engineered Soil Cover	$ 12,000	$ 120,000	$ 24,000	$ 240,000	$ 41,000	$ 410,000
5C - Ex-Situ Capping with a Vegetated Surface	$ 12,000	$ 120,000	$ 24,000	$ 240,000	$ 41,000	$ 410,000
5D - Ex-Situ Capping with a Wood Chip Surface	$ 12,000	$ 120,000	$ 23,000	$ 230,000	$ 40,000	$ 400,000
6 - Tilling/Soil Blending	$ 10,000	$ 100,000	$ 18,000	$ 180,000	$ 27,000	$ 270,000
7 - Fencing	$ 8,000	$ 80,000	$ 8,000	$ 80,000	$ 8,000	$ 80,000

Note: Values have been rounded to two significant figures.

Table 6
Institutional Protection Measures

Case Study	Institutional Protection Measures Implemented	Cost
Bunker Hill Superfund Site, Idaho	Establishing and enforcing institutional protection measures. Implementing a public education/outreach program. Providing technical assistance and services.	$175,000/yr
Barber Orchard, North Carolina	Implementing a public education/outreach program	NA
Mount Laurel Township, New Jersey	Requirements to establish a deed notice for contamination contained on-site. Distribution of information on historic contamination and health impacts.	NA
Verdese Carter Park, Oakland, California	Implementing a public education/outreach program. Providing technical assistance and services.	NA
Lowell Brownfields Redevelopment, Lowell, MA	Implementing a public education/outreach program.	One-time $92,000 grant

NA = Not Available

ATTACHMENT 1

Summary of Costs for Protective Measures